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RESEARCH PAPER

A Comparison of Productivity in Five Small-Scale Harvesting Systems

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Abstract The use of small-scale harvesting equipment continues to grow in forestry in many regions of the world. This equipment includes various devices and methods used to harvesting that generally are smaller, less expensive and less productive than advanced forestry machines. The objective of this study is to compare the efficiency of five alternative extraction methods implemented in a harvesting unit located in a mixed beech and oak forest ecosystem in northwestern Turkey. A continuous time study was conducted during primary transport operations that included skidding with animal power, skidding with farm tractor, hauling with farm tractor, hauling with forest tractor, and extraction by skyline. Timber was skidded uphill on a skid trail, and an average skidding distance of 100 m for all haulage methods was considered. Average slope of the harvesting unit ranged from 20 to 40 %. Average productivities for respective haulage methods were 3.80, 6.25, 2.80, 5.25 and 10.09 m^3/h. Significant differences were found between productivity of haulage methods using one-way analysis of variance. The extraction by skyline, skidding with farm tractor, and hauling with forest tractor were determined to be the most statistically different methods, the productivity of these methods was found significantly higher than the other methods. Skid trails are useful for shortening distances during forest operations and skidding with farm tractor is a productive method in small-scale forestry of Turkey.

Keywords Farm tractor · Log skidding · Primary transport · Timber extraction · Turkey

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Introduction

Log extraction is an important phase of forest harvesting operations. The use of mechanical power instead of animal power and manpower is becoming more widespread in small-scale forestry operations. Log extraction from a harvesting unit usually requires that the wood products spread over a large area are to be brought together under difficult transportation condition which constitutes the most expensive phase of timber harvesting (Bayoglu 1985). In many regions of the world, small-scale harvesting machines have been used in forestry where terrain condition and size of forest operations are not limiting (Akay 2005). In addition to lower purchase and operating costs, small-scale technologies have greater flexibility, easier portability between work sites and easier maneuvering in high stand density, resulting in potentially less impacts on the environment (Updegraff and Blinn 2000).

In some cases, various animal species (oxen, horses, buffalos and mules) have been used for skidding operations (Shrestha 2002; Jourgholami 2012). The maximum slope suitable for animal skidding is about 28 % (Lihai et al. 1996). Oxen are commonly used for skidding in Turkey because of their strength and docility. However, the use of animal skidding in Turkey has decreased markedly due to high cost and low productivity in recent years. Farm tractors are used for various forest harvesting tasks including felling, processing, extraction and transportation (Spinelli and Magagnotti 2012), and are particularly efficient in small-scale forestry (Johansson 1997; Ozturk 2010). Farm tractors attached to a winch system can skid logs downhill, on land with up to 25 % slope (Akay 2005), and are widely used for log extraction, skidding and loading operations after some modifications in Turkey. These include various types and size of tractors, as well as MB Trac skidders (Ozturk 2010). The latter skidders with cable systems are used mainly by Forest District Directorates. Cable systems are commonly used on more difficult and sensitive sites with steep slope.

Log skidding is probably the simplest harvesting task which requires relatively low investment in specialized equipment. Frequently, logs are pulled by the tractor with a winch, which is also used to lift the log ends off the ground during skidding (Spinelli and Magagnotti 2012). A winch system can be fitted to any tractor at a low cost. This system can be used for part-time forest operations, and has high potential for effective deployment in developing countries (Ladrach 2004). General statistical functions can be fitted to performance data to predict the productivity of skidding with tractor under a wide range of work conditions (Spinelli and Magagnotti 2012).

It is essential to determine the machine efficiency in skidding operations (Heinimann 1999) and to choose equipment with high efficiency for the particular environmental conditions. Many studies have been carried out on productivity of skidding operations and factors influencing machine productivity. These studies have revealed that skidding cycle time is affected mainly by skidding distance, terrain conditions, ground slope and log size (e.g. see Najafi et al. 2007; Behjou et al. 2008; Ghaffariyan et al. 2012; Gilanipoor et al. 2012). On relatively flat sites, there may be many options available for machinery and methods while on more difficult sites the options become limited (Russell and Mortimer 2005). Timber harvesting may cause some environmental problems including increasing the

amount of the sediment leaving a forested watershed (Kara et al. 2012). Most of the previous studies have been focused on productivity and cost of skidding equipment, with lack of attention to environmental impacts of alternative skidding methods.

The objective of this study has been to determine the most suitable small-scale log extraction equipment and method with high productivity under particular terrain conditions, skidding distance and forest products. The study compared five alternative log extraction methods (animal power, skidding with farm tractor, hauling with farm tractor, hauling with forest tractor, extraction with skyline) implemented in one harvesting unit located within a forest area of the western Black Sea region of Turkey in 2011. In this context, a continuous time study was undertaken and data analysed with analysis of variance to determine the appropriate method with respect to productivity and environmental impact.

The Study Area and Research Method

The study was conducted within the borders of the Devrek Forest District Directorate, one of the richest areas in terms of forest resources in the western Black Sea region of Turkey, with 68 % of the land covered with forests and heath. Slope ranges from 30 to 70 %. Almost all (99 % by area) of Turkish forests are owned by the government, whereas private forests have an important role in forestry in most of the European countries.

Harvesting operations in the region are performed using traditional methods including use of animal power for skidding and tractors for winching and skidding. The application of advanced mechanized harvesting is limited because harvesting machines are highly expensive and mechanization is considered to have negative effects on employment. The total number of the members of the forestry cooperatives, forest villagers and seasonal workers employed in forestry is about 200,000 (Ozden et al. 2011). These workers are not employees of professional contractor teams, but rather live in the local villages. In addition to their income from agricultural activities, many forestry workers earn a substantial proportion of their income from harvesting and transportation of forest products (Yoshimura and Acar 2004).

Time measurements in the area were conducted during the timber harvesting practices. Compartment 10a (harvesting unit) of Devrek Forest District Directorate was chosen for the research. This compartment (Fig. 1a) was harvested in accordance with the forest management plan over April to June, 2011. The compartment has typical land characteristics of the region and is suitable for implementation of various extraction methods. The average slope of the compartment was about 30 % ranging from 20 to 40 %. The stand type was a mixture of beech (*Fagus orientalis* Lipsky) and oak (*Quercus* ssp.). The average skidding distance considered in this study was 100 m for all extraction methods. Timber was skidded uphill except for skidding with animal power on skid trails.

Productivity analysis was conducted for five alternative logging methods. These are hauling with farm tractor (Fig. 1b), skidding by animal power (Fig. 1c),

Fig. 1 **a** Topography map of the study site (1/25000) **b–d** Some hauling methods in the region

skidding with tractor (Fig. 1d), hauling with MB Trac 900 forest tractor, and extraction with skyline. Two oxen were used for the method of skidding by animal power, while an Erkunt 4 × 4 farm tractor was used for the method of skidding with tractor. A logging winch mounted on the farm tractor, a logging winch mounted on the MB Trac 900 forest tractor and a Koller K300 yarder were used for hauling with farm tractor, hauling with forest tractor and extracting with skyline, respectively.

The operators of the machines were generally informed about the research prior to operation. However, in order to ensure routine daily practices, they were not interfered with during the practices regarding their manner and method of work practices. In a time study, it is necessary to eliminate the influence of the worker's performance especially when alternative methods are conducted in various places by various workers (Samset 1990). Therefore, workers with at least 5 years experience were chosen. The harvesting practice was continuously controlled and time measurements were made regularly with a milliseconds precision timepiece in order to observe the overall work. In order to compare alternative extraction methods, 30 trees were chosen randomly, and all the measurements were made upon these trees for each experimental treatment. The measurements aimed to determine the efficiency of each method. The use of the similar logs for each method was thought to provide the most accurate values in terms of productivity. The logs used

in the study were chosen among the logs that range from 20 to 50 cm in diameter, and logs that range from 1.5 m to 4 m in length. The volume of logs was calculated according to Huber's formula. The diameters and lengths of the transported logs were recorded, and their volumes were calculated.

The time of each phase of work moving the trees from the stump to the roadside was measured and manually recorded on prepared forms. These forms were arranged separately for each skidding method. In addition, skidding or hauling distance, slope and the direction of skidding were measured and recorded on the recording forms.

The continuous time study method was used as the time measurement method. A time-motion study was used to evaluate equipment productivity, and identify those variables that are most likely to affect it. According to this method, the timepiece was started at the same time as the skidding practice, and the values at the end of each work phase and the total time of the overall processes were recorded.

Arrival times of the animals to the loading point and of the loading, skidding and unloading processes were determined for the method of skidding by animal power. Arrival times of the tractor to the loading point and of the loading, skidding and unloading processes were determined for the method of skidding with tractor. Time from attaching the winch hook to logs and of the loading, haulage and unloading processes were determined for the methods of hauling by cable with farm tractor and hauling by cable with forest tractor. Empty loading time (arrival of the carriage to the loading point, then releasing of the crane hook, pulling off the hook towards the product and fastening it), and of the skidding (pulling of the product towards the carriage, then pulling of the loaded carriage to the unloading point, then releasing of the loaded hook) and unloading processes (unfastening of the load, then pulling of the empty hook towards the carriage) were determined for the method of extraction by skyline.

Productivity achieved throughout the extraction practices was calculated according to Eq. 1 (Acar 1995; Mousavi 2009) as the total time of the work including loading–unloading processes;

$$P = \frac{60 \times Av}{(Ld + Ud) + [(Rd + Cd) \times (Ed/Ad)]} \quad (1)$$

where P is productivity in (m^3/h), Ed is expected haulage distance (m), Ld is loading time (s), Av is average volume of the product skidded for each haulage step (m^3), Ud is unloading time (s), Rd is time of release of the empty hook (s), Cd is time of hauling by cable (s), and Ad is average haulage distance (m).

The mean and standard deviation were calculated for each variable measured. An analysis of variance was performed using the productivity data obtained through the measurements to determine whether there was a statistically significant difference among the extraction methods, then a multiple comparison of means test was conducted to identify significant differences between extraction methods. One-way ANOVA and Duncan's tests were performed at the 5 % significance level. Finally, the most suitable equipment and method were determined with respect to productivity according to the results of the time study and statistical analysis (Fig. 2).

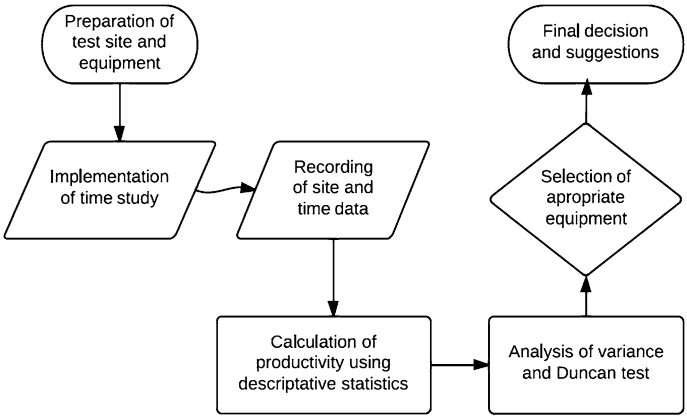

Fig. 2 Flowchart of the research methodology for productivity analysis

Results

Time measurements and log volumes within cycles obtained from five alternative extraction methods were recorded and evaluated, and then productivity values were calculated. Statistical data obtained through the evaluation of the measurements is presented in Table 1.

According to the average values, the longest time among the work phases of skidding by animal power was found to be the arrival time from roadside to the loading point, which was 4.98 min. It constituted 42 % of the total time of the work. Reaching the upper loading point was difficult and time-consuming for the oxen because of the top-down skidding. The longest time among the work phases of skidding with a tractor was found to be the skidding time on the ground, which was 3.12 min, or 40 % of total work time. The longest time among the work phases of hauling with farm tractor was found to be the haulage time, which was 14.35 min. It constituted 86 % of the total time of the work. This probably resulted from the fact that the machine pulled the logs at a constant speed, and that the logs were obstructed by standing trees.

Table 1 Average times per operation stage for each extraction method (min)

Operation stages	Extraction method				
	Animal power	Tractor skidding	Tractor cable	Forest tractor	Skyline extraction
Arrival time to the loading point	4.98 (0.73)	1.72 (0.50)	1.69 (0.56)	2.56 (0.64)	0.92 (0.18)
Loading time	2.56 (1.44)	1.99 (1.28)	0.25 (0.18)	0.42 (0.48)	1.01 (0.32)
Skidding/hauling time by cable	3.48 (1.94)	3.12 (2.22)	14.35 (4.53)	6.57 (3.49)	2.37 (0.38)
Unloading time	0.97 (0.57)	0.90 (1.88)	0.41 (0.80)	0.13 (0.15)	0.28 (0.10)
Total time	11.99 (2.63)	7.73 (3.64)	16.70 (4.53)	9.67 (3.41)	4.57 (0.40)

Average values and standard deviations (in parenthesis)

Table 2 Productivity values of extraction methods (m^3/h)

Extraction method	Mean	SD	Minimum	Maximum
Animal power	3.80	1.76	1.04	7.58
Tractor skidding	6.24	2.91	2.35	14.45
Hauling with farm tractor	2.80	1.39	0.92	6.91
Hauling with forest tractor	5.25	3.20	1.05	14.07
Extraction with skyline	10.09	3.99	2.83	20.34

The longest time among the work phases of hauling with forest tractor was found to be the haulage time, which was 6.57 min. It constituted 68 % of the total time of this work. This is probably because the machine pulled the logs at a constant speed. Moreover, the hauling speed of the forest tractor was observed to be higher than the speed of the farm tractor. The longest time among the work phases of skyline was found to be the pulling of the loaded carriage to the unloading point, which was 2.37 min. It constituted 58 % of the total time of the work.

A statistical summary of the data regarding the five alternative extraction methods is provided in Table 2. The two greatest average productivities (m^3/h) collected during the extraction operations, given a skidding distance of 100 m, were 10.09 and 6.24 for the methods of extraction by skyline and skidding with farm tractor, respectively. Notably, productivity was lowest using hauling with farm tractor (Fig. 3).

As shown in the Fig. 3, skyline extraction and tractor skidding operations have high productivity in the low total time region according to the distribution of the data. On the other hand, farm tractor cable and animal operations have low productivity in the high total time region.

The results of the analysis of variance, which was conducted in order to determine whether there was a statistically significant difference among the extraction methods by using the productivity values obtained through the measurements for each method, are given in Table 3. The ANOVA test statistics (F-value = 24.256, P value = 0.000) indicate a significant difference between productivity of the extraction methods.

The multiple comparison test on means (Duncan's test) identifies which treatments differ significantly. As indicated in Table 4, the productivity of the skyline method was found to be significantly higher than that of the other methods. Ranked second in terms of productivity were skidding with farm tractor and hauling with forest tractor. Skidding by animal power and hauling with farm tractor had the lowest productivity values; use of these former methods is clearly undesirable because they allow the top-down skidding only.

Discussion

The greatest average time measurement among the extraction methods considered was related to skidding time except for animal power, for which the greatest value corresponds to the arrival time. The percentage of skidding time to total work time

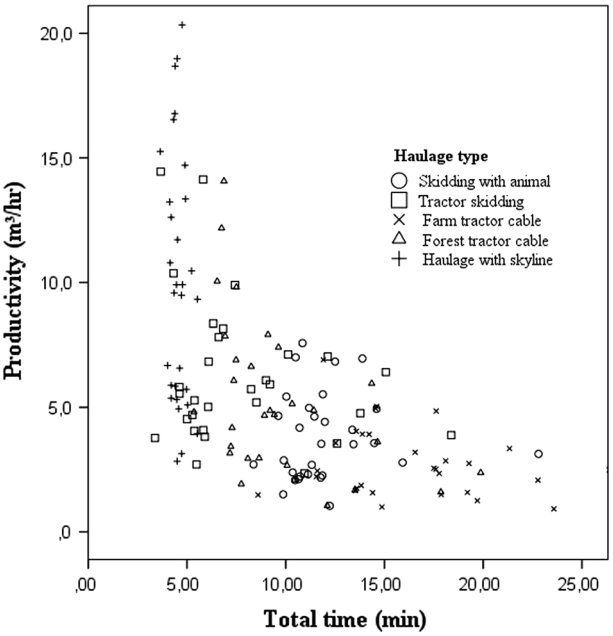

Fig. 3 Relationship between total time and productivity of hauling methods

Table 3 Results of the analysis of variance regarding the extraction methods

Source of variation	Sum of squares	Degree of freedom	Mean square	F	Sig.
Between extraction methods	954.960	4	238.740	24.256	0.000
Within extraction methods	1427.187	145	9.843		
Total	2382.147	149			

Table 4 Results of the multiple comparison test on means applied to productivity of extraction methods (m^3/h)

Extraction methods	Group 1	Group 2	Group 3	Group 4
Hauling with farm tractor	2.80			
Animal power	3.80	3.80		
Hauling with forest tractor		5.25	5.25	
Tractor skidding			6.24	
Extraction with skyline				10.09

was found to be 40 % with farm tractor, 86 % with tractor cable, 68 % with forest tractor, 58 % with skyline. Average productivity values (m^3/h) for the five alternative extraction methods and skidding distance of 100 m were 3.80, 6.24, 2.80, 5.25 and 10.09 for the methods of skidding by animal power, skidding with farm tractor, hauling with farm tractor, hauling with forest tractor and extraction by

skyline, respectively. Gilanipoor et al. (2012) found that average productivity rate ranged from 2.43 to 2.60 m^3/h in an average skidding distance of 665 m when a farm tractor was used. Acar (1997a) observed an average productivity of 4.18 m^3/h in a skidding distance of 100 m with a farm tractor, while Menemencioglu and Acar (2004) found a value to be 6.35 m^3/h. Also, Menemencioglu and Acar (2004) determined the average productivity was 6.33 m^3/h for the method of hauling with MB forest tractor over a skidding distance of 50 m. Moreover, Acar (1997b) observed a productivity value of 3.31 m^3/h with the use of the Koller K300 skyline over a distance of 250 m. Given the results of the previous studies performed under similar conditions, the findings of the current study seem to be logical.

Productivity of animal skidding was found to be significantly lower than that of most other methods. However, it is superior to heavy machine skidding in terms of environmental damage to residual stands and soil disturbance (Lihai et al. 1996). In a study conducted by Jourgholami (2012), hauling distance was found to be the greatest component of total cost during wood extraction by animal (mule). Extraction by winch or animal results in higher costs compared with the use of skidders (Mederski 2006).

While extraction by skyline was determined to be the most efficient extraction method, the slope of the land needs to be greater than 50 % in order to use this method. In addition, cleared corridors need to be established within the forest in order to install the skyline. After the installation of the skyline tree marking is conducted on suitable terrain, with a width of 5 m at 50 m intervals. If the corridors are narrower than 5 m, the carriage over the trees and dragging out of the compartment may damage the nearby standing trees, thus decreasing the productivity of the stand. Timber extraction with skylines is not preferred by the harvesting workers in Turkey. Skylines are owned only by the forest directorates of government, but can be hired by forest villagers, the cost being on an hourly rate or based on amount of the products extracted. A further problem is that the operators of the skylines are not sufficiently skilled and do not come to work regularly. Therefore, it is necessary that the use of this highly efficient method is encouraged and instructions and support are provided by the forest directorates of the government.

The greatest loss of time occurs because logs become caught in standing trees and stumps in the course of hauling with farm tractor or with forest tractor. Efficiency could be increased by reducing the delay time thanks to well-designed work organization (Ghaffariyan et al. 2012). When the trees are skidded, one worker has to free the trees from where they are caught, which is an extremely difficult and time-consuming task. Therefore, at least two workers excluding the operator need to be available on the site during the hauling of the trees by farm or forest tractor.

The use of the farm tractor is widespread because, like forest tractors, many affordable 4 × 4 farm tractors have appropriate technical equipment for the terrain conditions and several items of forestry equipment (loading, skidding and road surface smoothing equipment) can be assembled on these tractors. The farm tractor was more expensive for the range of extraction distances tested (150–500 m), suggesting that it should be used only as a support unit and for extraction distances of less than 150 m (Spinelli et al. 2004). In order to maintain the effectiveness of

small-scale harvesting equipment, the harvesting managers need to develop an effective logging plan in advance. As a result of this study, the most appropriate method for the haulage operations in the western Black Sea region was skidding with farm tractor. In this context, the appropriate tractors and skid roads should be planned in the forests and the farm tractor should be encouraged as a productive method in small-scale forestry of Turkey.

The use of the farm tractor is widespread throughout Turkey because, like forest tractors, many affordable 4 × 4 farm tractors have appropriate technical equipment for the terrain conditions and several items of forestry equipment (loading, skidding and road surface smoothing equipment) can be assembled on these tractors. Farm tractors are well suited as support units for extraction distances of less than 150 m (Spinelli et al. 2004). It is concluded from this study that the most productive method, appropriate for haulage operations in the western Black Sea region, is skidding with a farm tractor. In order to maintain the effectiveness of small-scale harvesting equipment, harvesting managers need to develop effective logging plans in advance. In this context, skid roads should be planned in the forests and use of farm tractors needs to be encouraged as a productive method in harvesting small-scale forestry of Turkey.

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